Scaling of discharge based XUV sources for metrology applications

Klaus Bergmann, Jochen Vieker, Alexander von Wezyk

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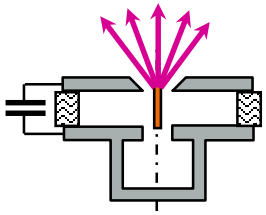
Overview

- Introduction
- Hollow Cathode triggered pinch plasma – basic principle
- Long term stability: influence of erosion on EUV emission
- Two stage electrode system: Concept
- Two stage electrode system: First results on 2.9 nm, 6.7 nm and 13.5 nm
- Summary

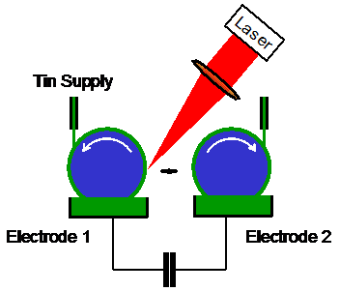
EUV sources at Fraunhofer ILT

Source concept:

HCT pinch plasma



Tin vacuum arc

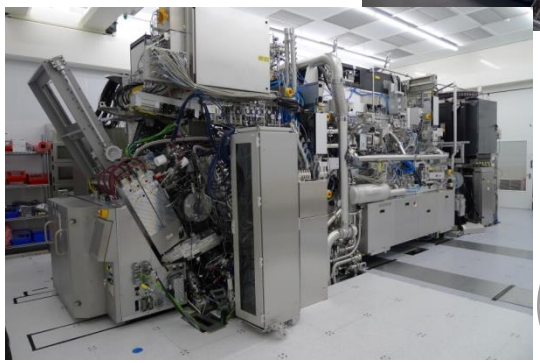


Partners:

research instruments

AIXUV EUV-Technology

PHILIPS



USHIO GROUP

XTREME technologies

Applications:

- EUV Lithography: Scanner
- EUV optics contamination studies
- In-house calibration of diagnostics
- Reflectometer for ML mirrors
- Reflectometer for surface analysis
- Water window microscopy (2.9 nm)
- Nano patterning
- Resist characterization
- Coherent diffraction imaging
- EUV microscopy – Defect inspection
- Photo electron spectroscopy
- Wavelength calibration

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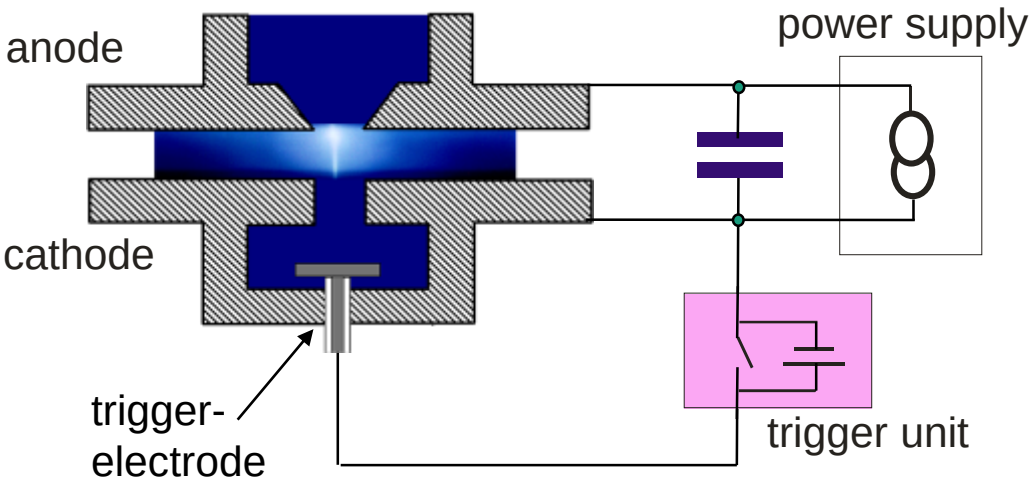
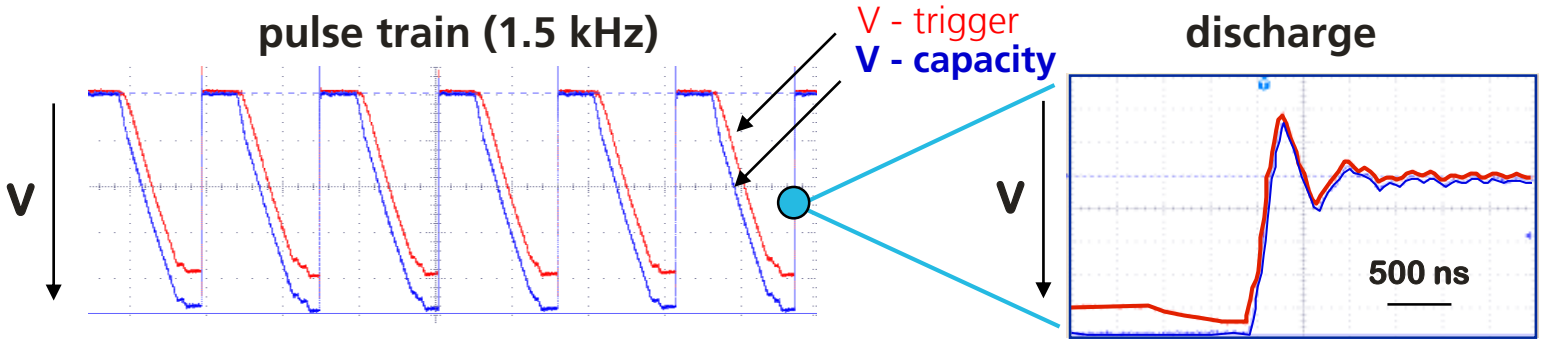
Hollow cathode triggered pinch plasma





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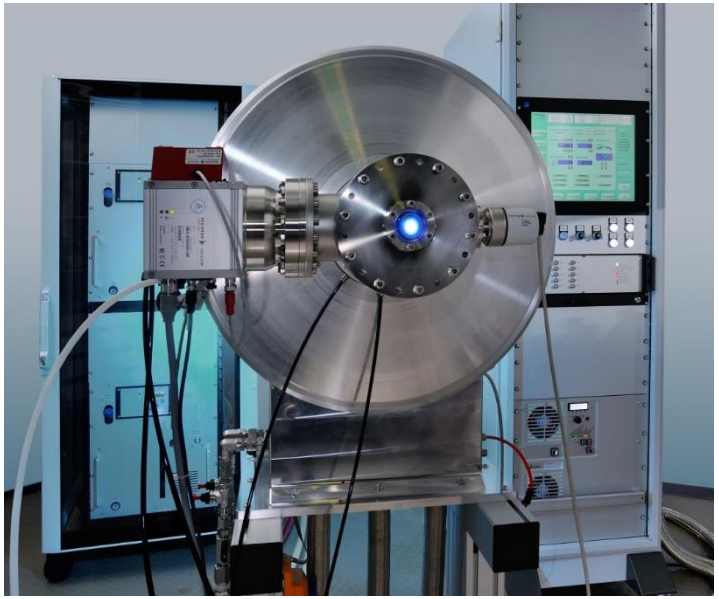
Fraunhofer ILT source : FS-series

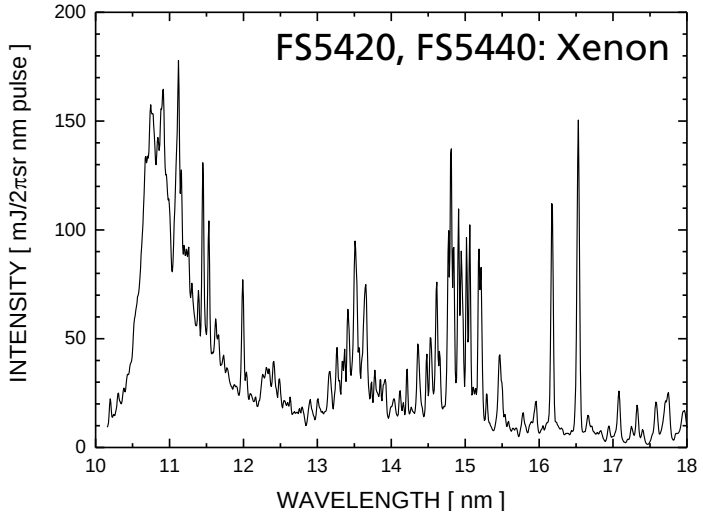


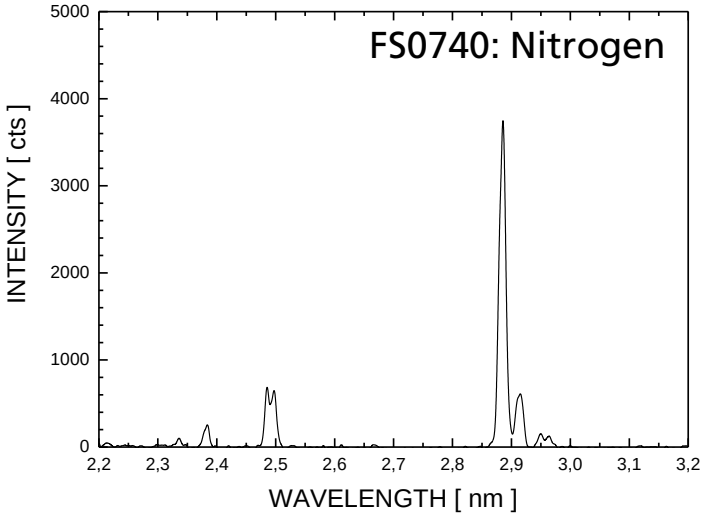
13.5 nm (2% b.w.)

- 40 W/2πsr
- 12 W/mm²sr

2.9 nm (line)

- 4.6 W/2πsr
- 4.0*10⁹ Ph/sr µm²s





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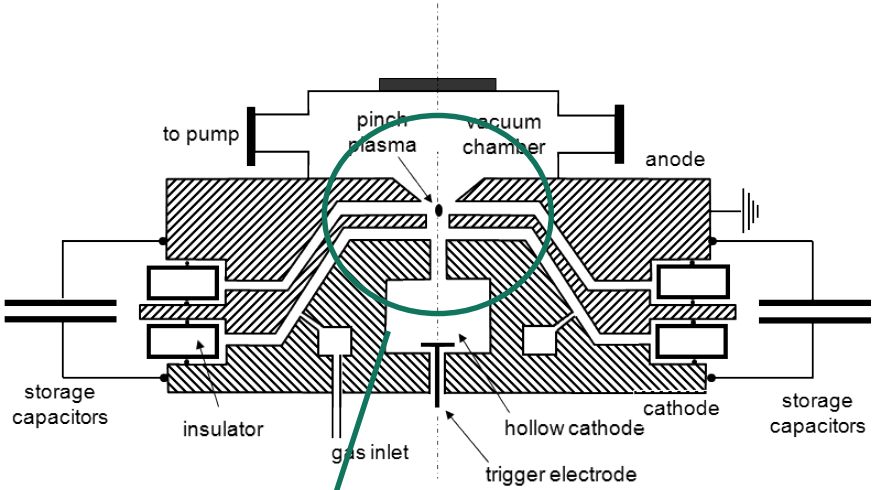
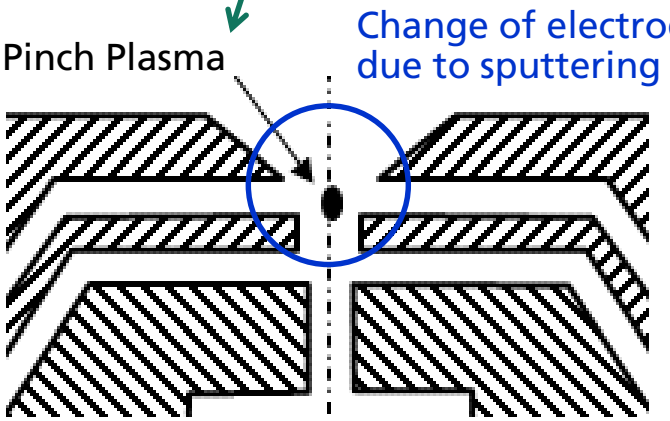
Power scaling, long term stability: tasks and actions





Questions:

- Influence of electrode shape (new, eroded) on EUV emission, re-deposition of material (→ improvement of long term stability)
- Influence of pressure distribution on source performance, interaction of hollow cathode ignition and electrode shape
- Scalability potential at higher or lower working gas pressures, currently ~ 10 - 20 Pa

Actions:

- Increase of operation parameter range using advanced trigger system
- Increase of operation parameter range using additional switch
- Parameter studies on electrode designs
- Test of sputter resistant materials

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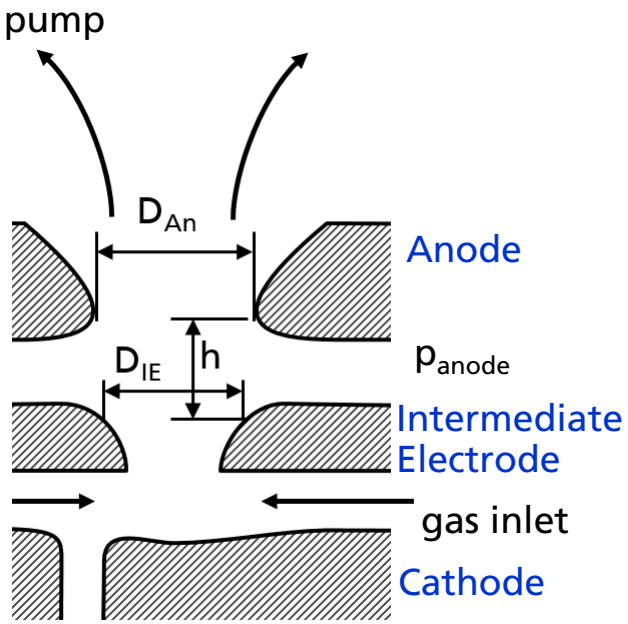
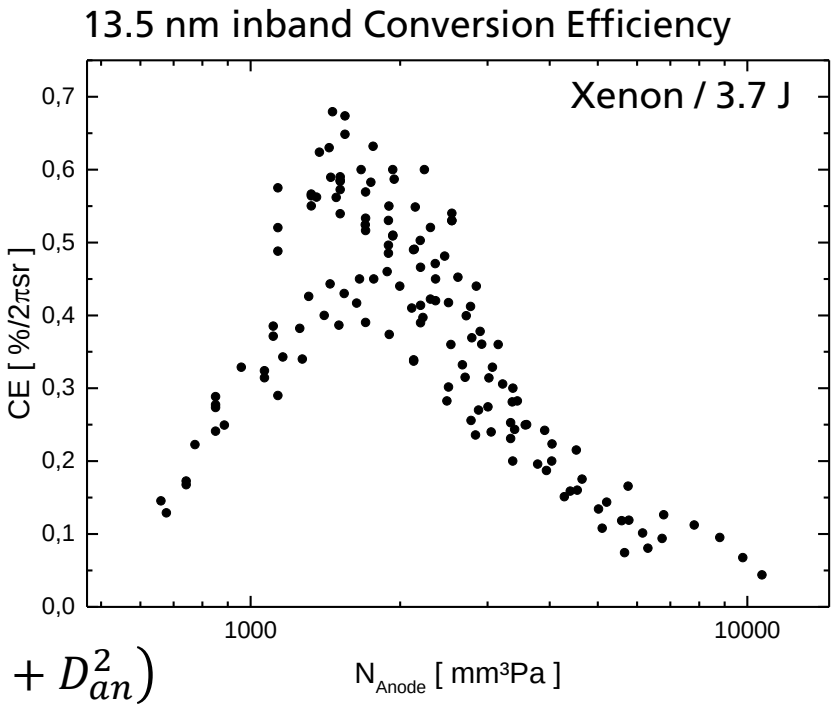
Conversion efficiency – Electrode shaping





$$N_{Anode} = p_{anode}\frac{h\pi}{12}\left(D_{ie}^2 + D_{ie}D_{an} + D_{an}^2\right)$$

- measurement of CE for several electrode configurations
- variation of anode pressure for each set
- similar behavior when taking N_{anode} as parameter
- increase of conversion efficiency up to 0.7 %

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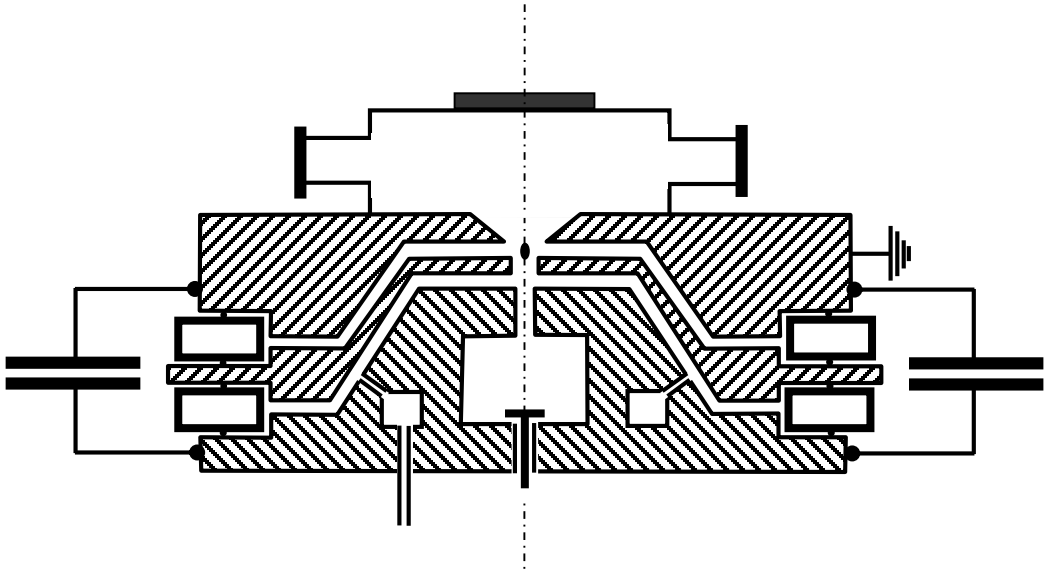
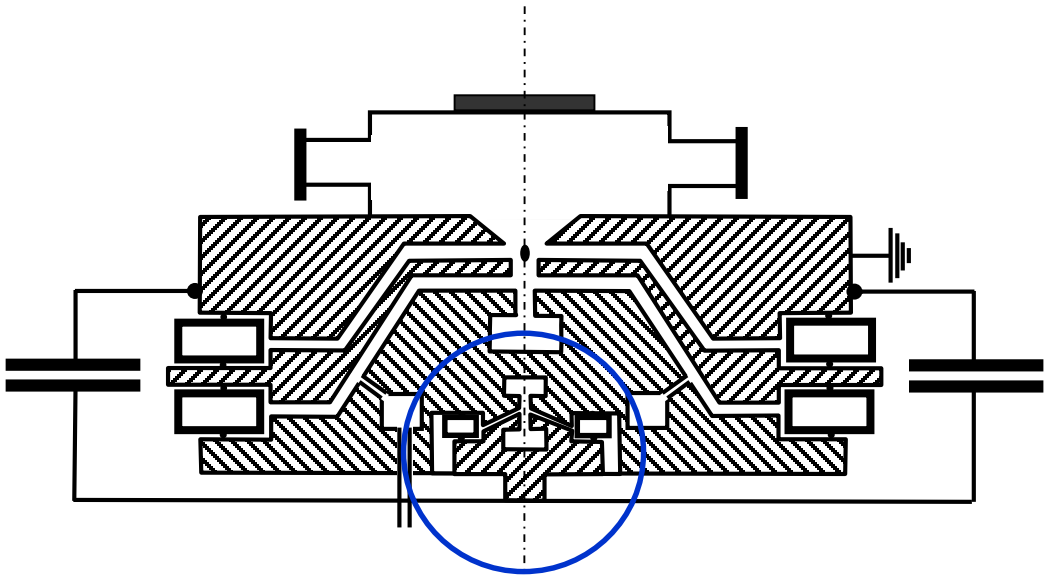
System with additional switch



System with additional switch



Pseudo Spark Switch
(operated with helium)

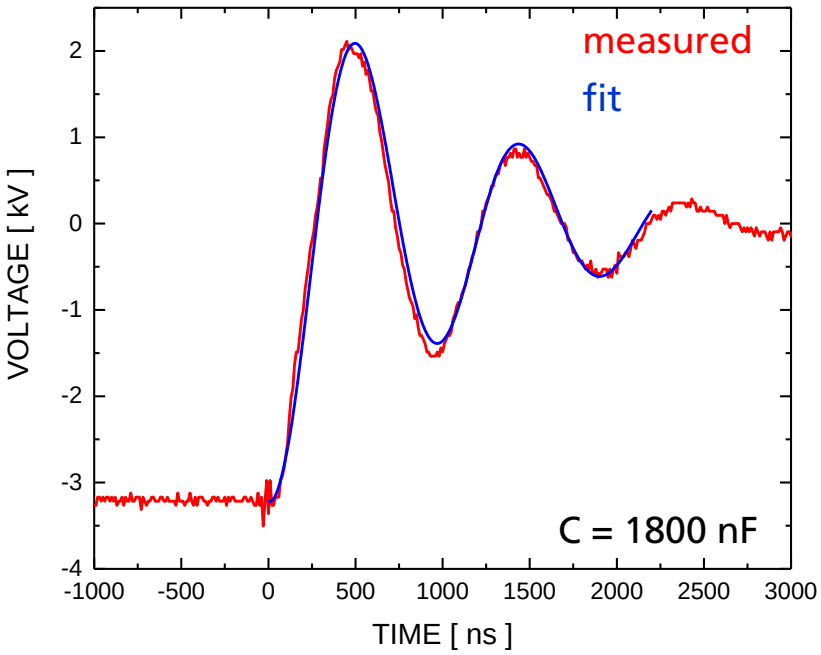
- access to larger working gas pressures
- possibility of pre-ionization
- de-coupling of EUV emission and switching
- frequency scaling and EUV emission can be optimized independently
- low inductance of the additional pseudo spark switch

more details in Ref.:

Bergmann, Vieker, von Wezyk, J. Appl. Phys. 120, 143302 (2016)

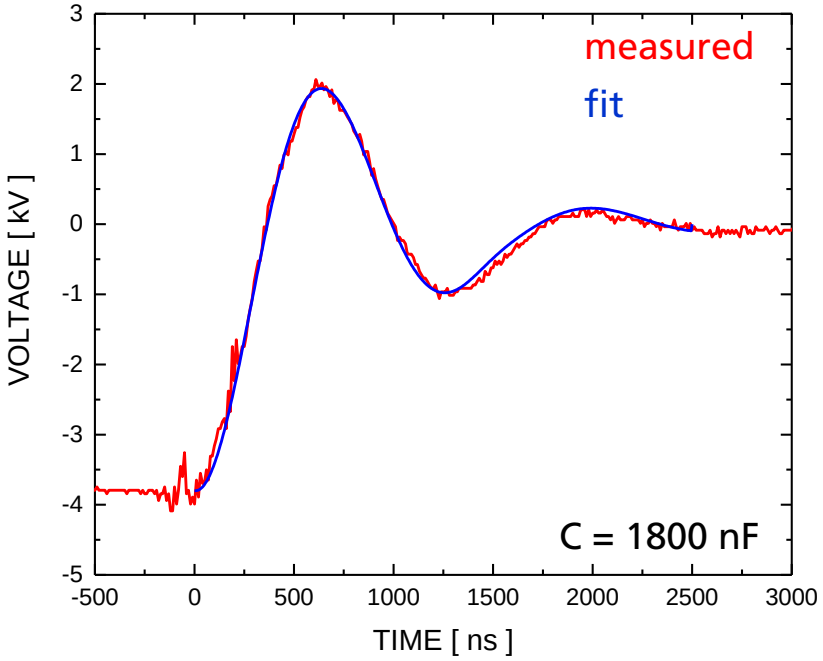
Electrical circuit parameters

without switch



L = 13 nH

with additional switch



L = 22 nH

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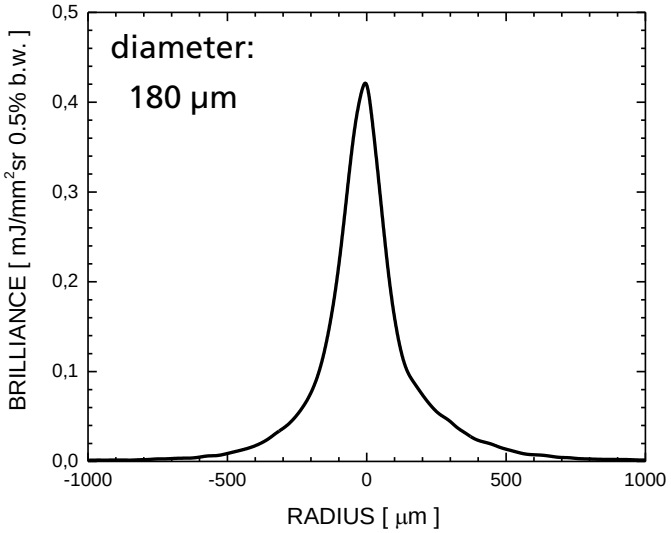
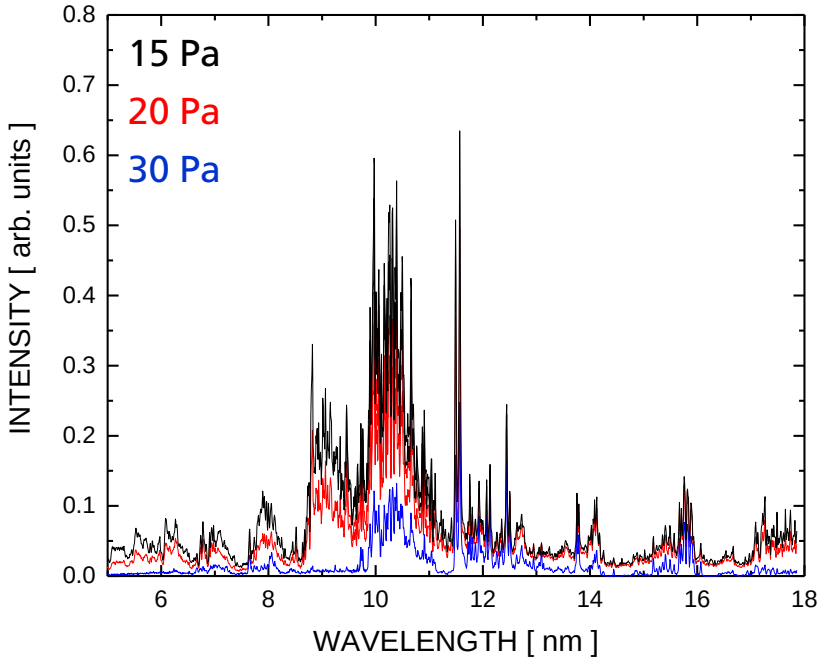
Emission spectra of Krypton – Pressure variation

- Pressure variation at fixed energy of 8.1 J
- Lowest pressure (15 Pa) is close to self-breakdown operation pressure
- ~ 0.75 smaller diameter with switch
- Peak Brilliance at 6.7 nm:
  self-breakdown: 11 mJ/(mm² sr nm)
  with switch: **13 mJ/(mm² sr nm)**



Spatial emission profile at 6.7 nm

Emission spectrum (raw data)



Diagnostics:

- Flat field spectrograph
- Calibrated energy monitor,6.7 nm
- Inband-camera for 6.7 nm

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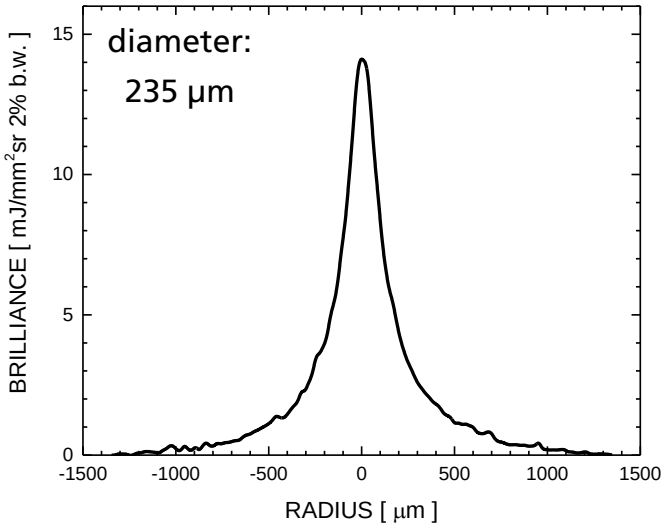
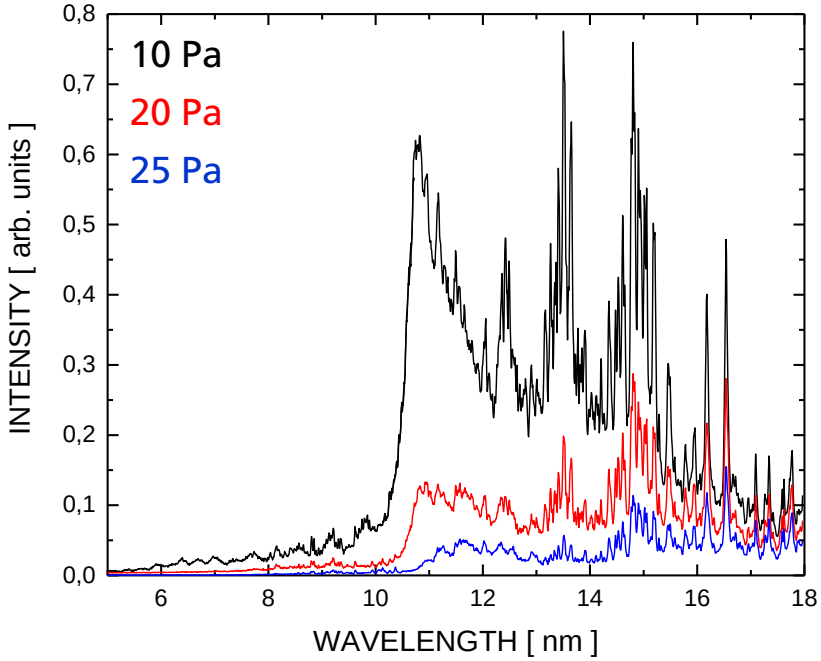
Emission spectra of Xenon – Pressure variation

- Pressure variation at fixed energy of 8.1 J
- Lowest pressure (10 Pa) is close to self-breakdown operation pressure
- ~ 0.75 smaller diameter with switch
- Peak Brilliance at 13.5 nm:
  self-breakdown: 37 mJ/(mm² sr nm)
  with switch: **52 mJ/(mm² sr nm)**



Spatial emission profile at 13.5 nm

Emission spectrum (raw data)



Diagnostics:

- Flat field spectrograph
- Calibrated energy monitor, 13.5 nm
- Inband-camera for 13.5 nm

v:<a11.2016.tagung.euv-source_workshop_2016.dpp scaling>S17_amsterdam2016.pptx

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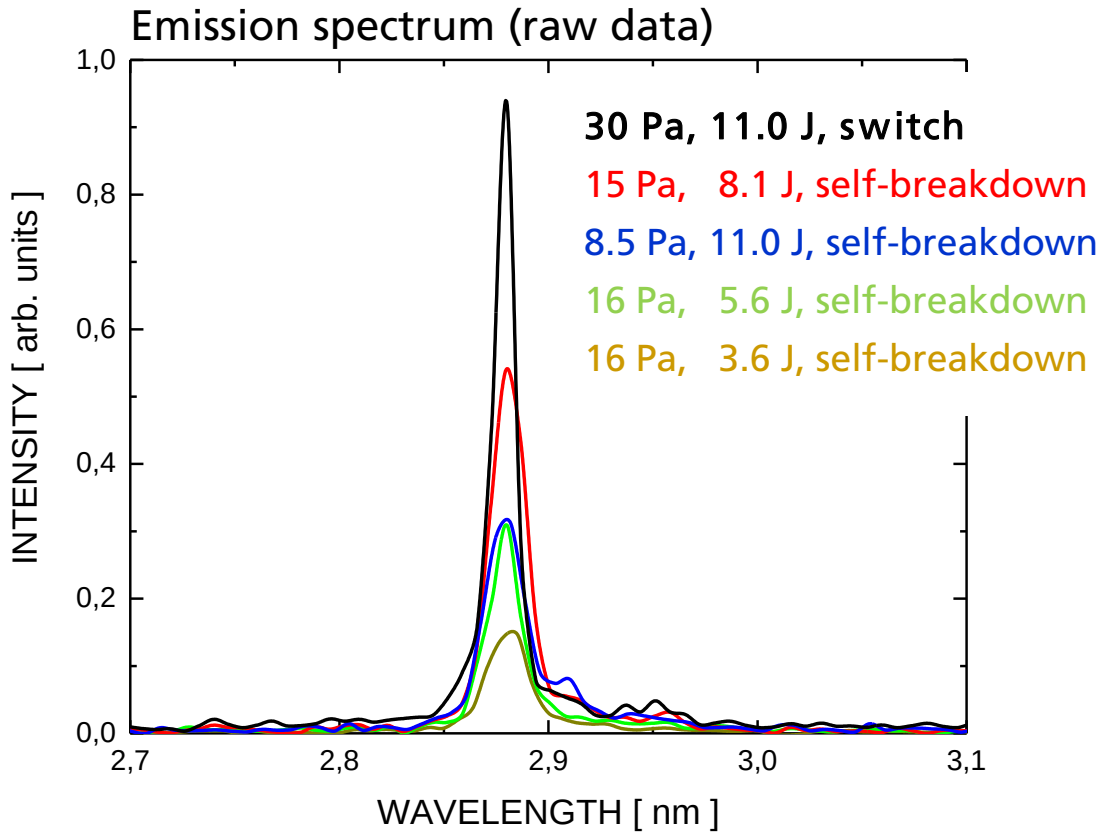
Scaling of nitrogen 2.88 nm He-α emission



Access to higher working gas pressure allows for more effective conversion of energy into water window radiation !

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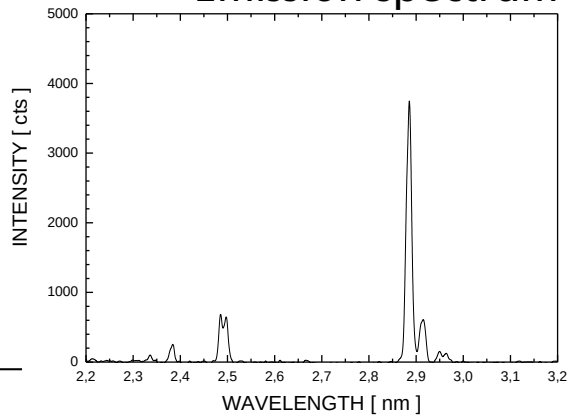
Emission at 2.88 nm: Increase of peak brilliance

- new system leads to smaller emission radius
- conversion efficiency for total 2.88 nm photon flux is similar
- peak brightness of

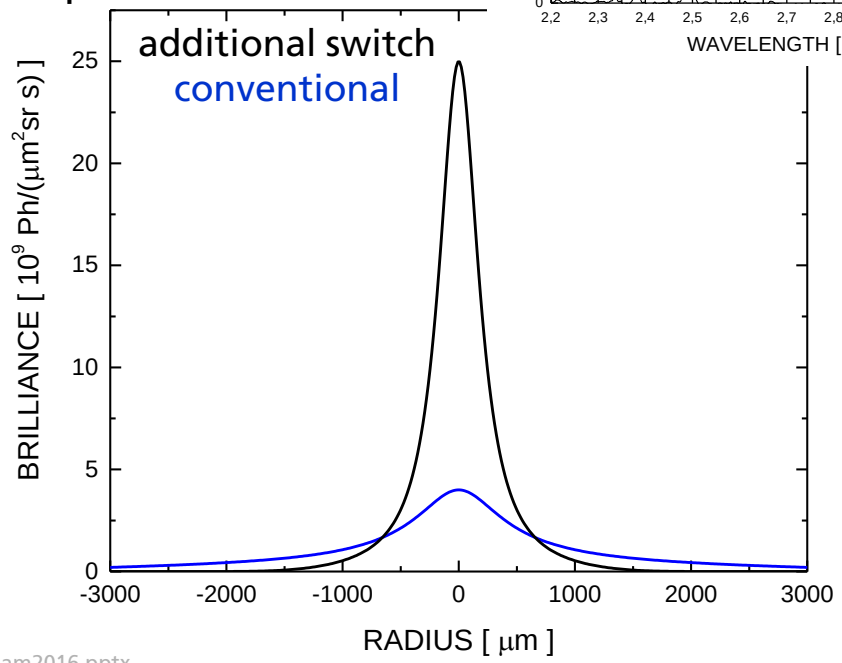
~ 2,5 * 10^{10} Ph/(µm²sr s)

is based on measured data per pulse and assumption of operation at 1000 Hz

Emission spectrum



Spatial emission profile at 2.88 nm



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Outlook: Discharge based soft x-ray microscope

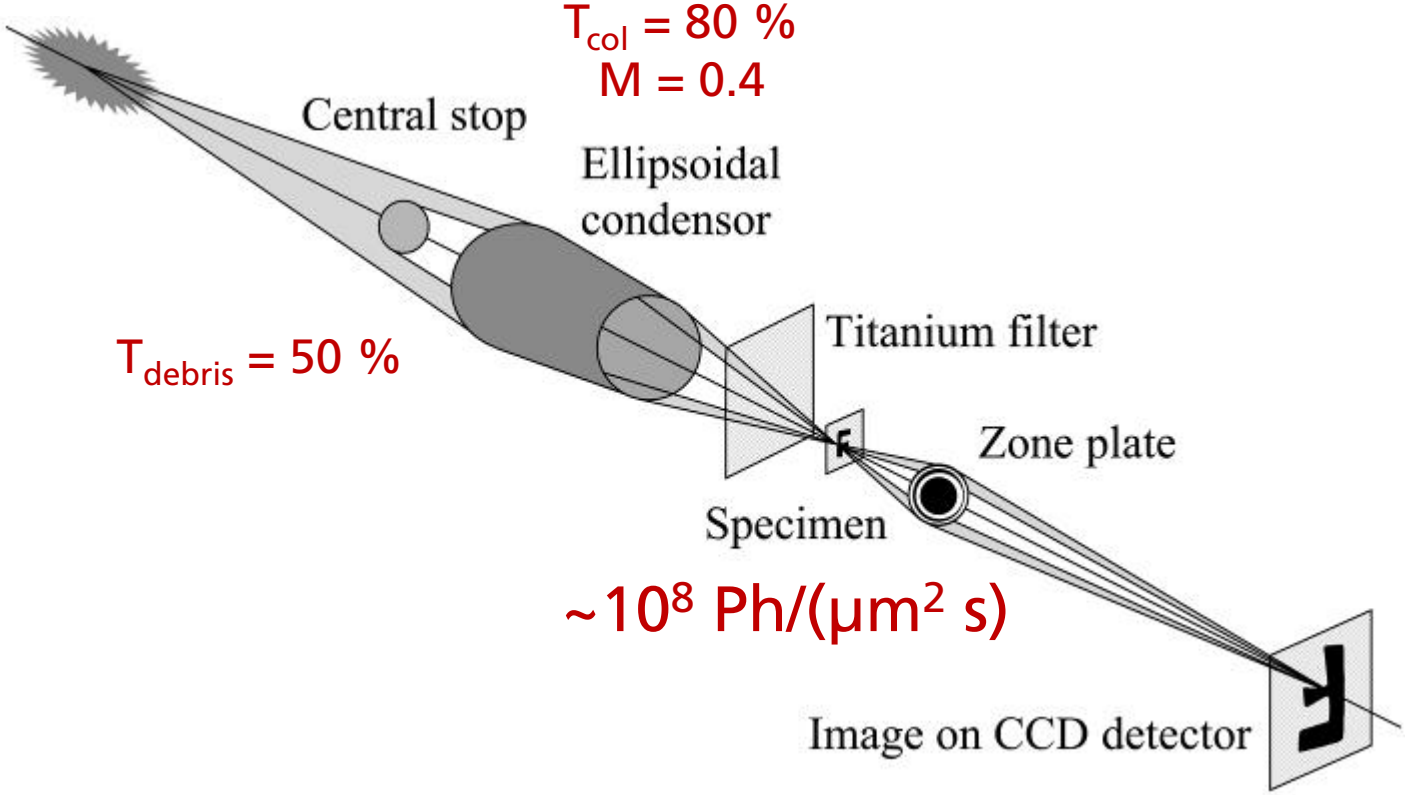
1000 Hz, 8 kW

$2{,}5 * 10^{10}$ Ph/(µm²sr s)

$\Delta\Omega = 1{,}5 * 10^{-3}$ sr

$T_{col} = 80\ \%$

M = 0.4



$T_{debris} = 50\ \%$

~10^8 Ph/(µm² s)

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Summary

- Progress in understanding of electrode shape – EUV emission

  → Increase of operation interval by adjusting the parameters
  → Design rules for electrode system with CE of 0.7 % or > 60W/(2πsr)

- Presentation of system with access to higher working gas pressure (smaller diameter – major improvement in 2.88 nm brilliance)

- Brilliance per pulse :

→ 6.7 nm, Krypton	: 13 mJ/(mm^2 sr nm)
→ 13.5 nm, Xenon	: 52 mJ/(mm^2 sr nm)
→ 2.88 nm, Nitrogen	: 2.5∗10^7 Ph/(µm^2 sr)

See Posters:

- (S83) Compact discharge based EUV source with high power and long maintenance interval, Jochen Vieker
- (S47) Alternative emitters for LPP sources around 6.x nm, Alexander von Wezyk

THANK YOU !!

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